AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

The African Continental Power Systems Masterplan

Support Studies – Battery energy storage systems (BESS)

African Union

THE AFRICA-EU PARTNERSHIP
LE PARTENARIAT AFRIQUE-UE

Africa-EU
Energy Partnership

African Union Development Agency - NEPAD
230 15th Road, Midrand, Johannesburg, South Africa
Tel: +27-11 256 3600
Email: info@nepad.org
Web: www.nepad.org
Twitter@Nepad_agency
#TheAfricaWeWant

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Introduction

Development of a continental master plan

The African Union (AU) has articulated a vision for a continent-wide interconnected power system (the Africa Single Electricity Market (AfSEM)) that will serve 1.3 billion people across 55 countries, making it one of the biggest electricity markets in the world. Interconnection offers immense technical and economic opportunity[1], while a fully integrated and competitive market will accelerate development and energy access across the continent. Increasingly, the enhanced system flexibility and resilience of an interconnected power system is also an imperative for a modern power system able to navigate the developments impacting global energy systems: growing shares of low-cost variable renewable energy; commitments to climate change and decarbonisation, decentralisation and democratisation of energy; intelligent grid infrastructure and digitalisation of the energy sector; infrastructure resilience in the face of climate risks; and the rise in energy storage technology and electric vehicles.

Concrete steps have been taken towards realising the broader vision described by the AfSEM together with the AfDB's new deal for energy and clean energy corridor concepts. Among these is the development of a Continental Power System Masterplan (CMP) expected to create the framework conditions that will allow countries to trade electricity to leverage national and regional surpluses and deficits through cross border power exchanges and inter power pool trade. This harmonized platform will aid optimised project decision-making regarding the location, size and timing of generation and transmission infrastructure investments.

The CMP is being developed under the governance structure of AUDA-NEPAD (the African Union Development Agency) with direction from ministerial committees to ensure political and technical alignment. Development spans two phases (Figure 1) and is implemented over several years, with targeted completion by the end of 2023.

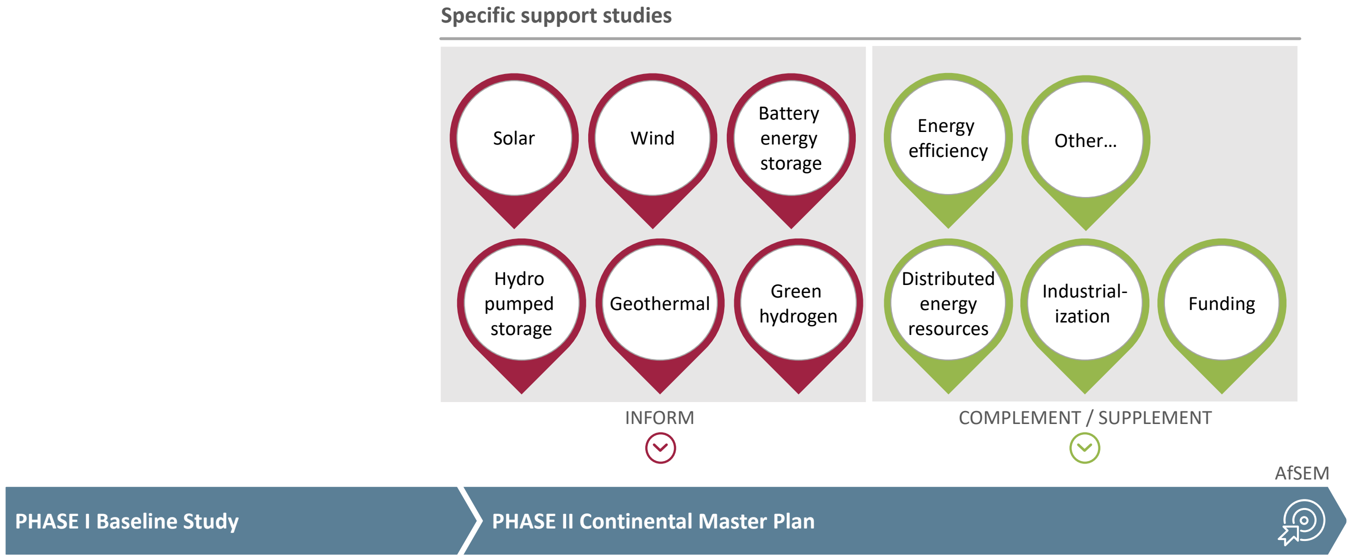

Figure 1: CMP development phases with input from specific support studies

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[1] Benefits include increased system reliability; access to more diverse generation resources; enhanced security of supply; improved system flexibility, redundancy, and resilience; reduced or deferred capital investments; diversified loads and improved load factors; and operational and maintenance efficiencies gains, among others.

In parallel, several studies are being developed to help refine and enhance the CMP (Figure 1). These specific support studies (SSS) aim to inform or complement the planning of the CMP, providing a clearer understanding of the potential contribution to the continental power system or the potential for adjacent developmental opportunities.

Battery energy storage as part of the continental power system

This summary provides an overview of the specific support study for **battery energy storage systems (BESS)** that was developed with support from USAID Power Africa. It considers the potential contribution from BESS to the power system, as well as opportunities, barriers or challenges and recommendations to achieve an optimal contribution to the continental power system.

BESS is another form of energy storage, similar to the more familiar pumped storage hydropower. Batteries do not generate electricity, rather their value lies in

(i) being able to provide “energy in the right form, at the right place, and at the right time”, as well as

(ii) a range of ancillary services that can enhance system stability throughout the electricity supply chain.

While it is not a conventional generation source, batteries play an essential role that enables the power system to incorporate variable renewable energy (VRE), distributed and embedded generation resources with multidirectional flows, electric vehicles, prosumers, and co-generation solutions. It also allows the system to accommodate changing consumer needs, applications and power system interfaces.

The CMP already reflects the planned addition of significant VRE onto national and regional power systems. The share of VRE is projected to grow from a very low base to approximately 38% of the installed capacity by 2040.

In this context, energy storage will be a critical component of a modernised power system, acting in a complementary or support capacity to the power system, to contribute the following:

- **Improved resilience**. More extreme weather events are already threatening grid reliability and conventional power generation capacity world-wide. Distributed energy storage systems can effectively contribute resiliency, provide backup power during power outages and help stabilise the grid.
- **Increased system flexibility and reliability**. Energy storage can absorb and manage fluctuations in demand and supply. Combined with modern inverters, it offers further flexibility to the power system with the ability to respond rapidly to (i) imbalances in supply and demand, (ii) changes in power flow patterns and fluctuations, and (iii) changes in power quality.
- **Enabling low-cost energy supply**. Energy storage enables (i) the integration of low-cost renewable energy technologies, (ii) grid optimization and (iii) deferral of expensive upgrades in power networks; all of which reduce the cost of electricity delivered to the consumer.
- **Meeting climate commitments.** By enabling a larger share of renewable energy, energy storage will also support the delivery of climate commitments for those countries that have developed climate action plans and committed to nationally determined contributions (NDCs).

This support role coupled with its unprecedented versatility and flexibility is what make energy storage systems valuable AND difficult to model and quantify their full potential and value to the power system.

While a separate investigation considered pumped hydro storage, this study specifically focuses on BESS and its potential contribution to the African power system. BESS are of particular interest as they offer dispatchable storage with sizing and locational flexibility i.e. allowing deployment at varying scales in proximity to the location where grid flexibility is needed. This focus on BESS is also cognisant of the World Bank Group's USD1 billion global battery storage programme, announced in 2018.

Resource potential

The potential for energy storage is dictated by the: (i) power system needs, (ii) availability of energy or electricity to store and (iii) availability of suitable and cost-effective battery options to deliver a storage service. The SSS assumes that enough energy will be generated to make BESS viable. It therefore considered technology options, costs and system needs to assess BESS potential.

Technology options

BESS includes multiple conventional and novel battery chemistries. The study identified seven[2] commercially available and eight emerging[3] battery options that are potentially relevant to Africa's current and future grid-scale energy storage requirements.

Among the commercial technologies, lithium-ion batteries are best known. They have been the dominant technology for grid-scale applications, representing almost 60% of global grid-scale BESS deployments in 2021. They are expected to retain dominance throughout the decade alongside a few other technologies[4] that are also expected to register sizable deployments by 2030.

Different battery options offer different characteristics[5] and are therefore suited to different system needs. This leads to two key concepts:

1. **Specific characteristics or attributes may be best suited to specific applications or grid requirements**. This means different battery options would be considered depending on the system need.
2. **All batteries can provide more than one service or application and can deliver these services in succession or in parallel**. By means of an example, a single battery could be used for both frequency regulation and arbitrage either at different times or simultaneously.

Energy storage requirements are expected to evolve with the evolution of the electricity generation mix and system operations. Four phases of energy storage adoption have been defined as shown in **Error! Reference source not found.**. The phases are described by the primary service(s) provided; the required storage duration; the required response speed; and a corresponding deployment scale (based on the USA experience, which will vary by territory). As seen for phase 3 and 4, long duration storage is increasingly an important requirement for grid scale BESS.

Although currently dominant, lithium-ion batteries are not anticipated to be the preferred long duration storage option, despite achieving longer discharge durations of up to eight hours and rapidly declining costs. Significant resources are being invested globally to advance battery technologies suitable for grid applications that are constructed of lower cost material, have lower environmental impacts, offer longer duration storage and greater cycle life. Several emerging technologies are already showing promise and are likely to dominate the mix post 2030.

This understanding of evolving system requirements and rapidly developing technologies **point to the importance of keeping policy and regulatory frameworks technology neutral to avoid technology lock-in at this early stage**.

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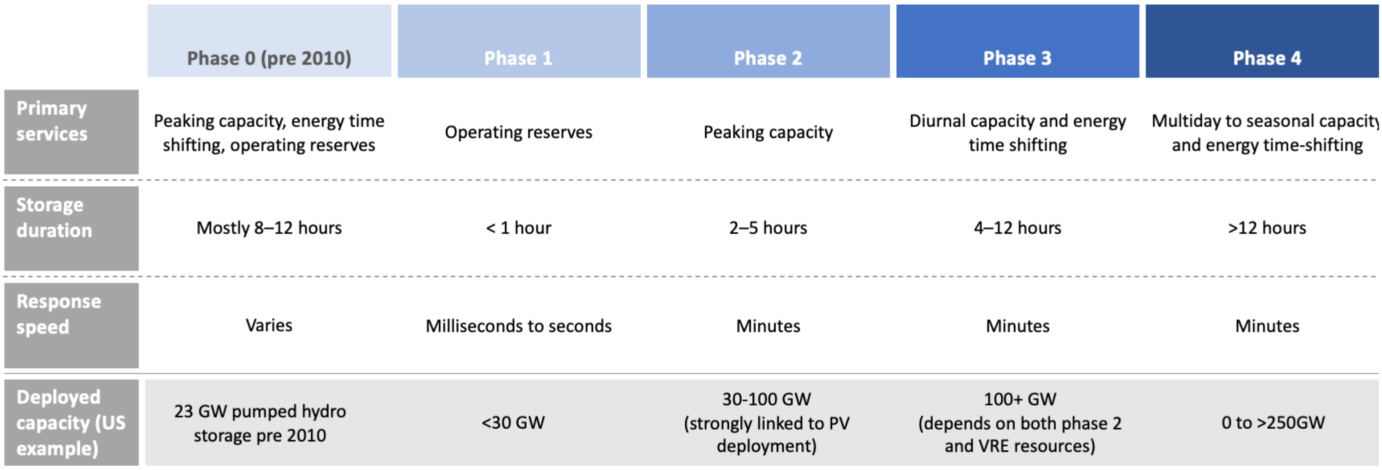
[2] Commercial: Lead-acid batteries (LAB), nickel-cadmium batteries (Ni-Cd), nickel-metal hydride (Ni-MH) batteries, lithium-ion batteries (LIB), sodium-sulfur (NaS), sodium-nickel chloride (NaNiCL2) and vanadium-redox flow batteries (VRFB)

[3] Emerging: polysulfide bromine (PSB), and zinc-bromine (Zn-Br), sodium-ion battery (NIB), zinc-air batteries (ZABs), iron-based batteries (IBBs), liquid-metal batteries (LMBs), sodium-iron chloride (NaFeCl2), and lithium-sulfur batteries (Li-S)

[4] Notably sodium-ion (commercial) and liquid-metal batteries (emerging)

[5] Different battery chemistries or technologies perform differently in terms of power rating, storage duration, cycling or lifetime, self-discharge, energy density, power density, efficiency, response time, charge time and environmental impacts.



	Phase 0 (pre 2010)	Phase 1	Phase 2	Phase 3	Phase 4
Primary services	Peaking capacity, energy time shifting, operating reserves	Operating reserves	Peaking capacity	Diurnal capacity and energy time shifting	Multiday to seasonal capacity and energy time-shifting
Storage duration	Mostly 8–12 hours	< 1 hour	2–5 hours	4–12 hours	>12 hours
Response speed	Varies	Milliseconds to seconds	Minutes	Minutes	Minutes
Deployed capacity (US example)	23 GW pumped hydro storage pre 2010	<30 GW	30-100 GW (strongly linked to PV deployment)	100+ GW (depends on both phase 2 and VRE resources)	0 to >250GW

Figure 2: Four phases of energy storage requirements corresponding with an evolving generation and mix and operating system.

Cost developments

How to quantify the cost of BESS

The seemingly simple question of costing and valuation of energy storage, including BESS, is complex and currently the subject of much academic research. The choice of BESS technology, their various levels of maturity, the different ranges of performance, the project size, the relevant grid use case(s) and even the placement in the power system all impact the cost and valuation. Given this understanding, the cost of energy storage is considered from two perspectives:

1. The simplest and most commonly reported is the **investment** or **installed capital cost** (USD/MW or USD/MWh) i.e. maximum MW capacity and duration of supply at peak capacity (MWh).
2. The second considers all lifetime costs of the ESS – charging, decommissioning and disposal. Two life cycle cost metrics commonly used are **levelized cost of storage** (LCOS)[6] and **annualised cost of storage**[7]. Both are defined analogously to the well-known levelized cost of energy (LCOE)[8] and calculated based on two different but standard methods of corporate finance. Both methodologies consider the cumulative lifetime energy discharged or power delivered.

Lifecycle cost metrics point to the importance of BESS asset utilisation as a critical cost consideration. A battery that stands idle, intended to provide backup services only or operating for a confined period for a single application only, are unlikely to achieve cost recovery.

This underscores the importance of BESS assets being optimally utilised to provide multiple services and generate multiple revenue streams. The range of potential services are discussed in Section 3 (Opportunities).

Cost trends and forecasts

Current projections foresee the global energy storage market grow to 358 GW/1,028 GWh by 2030, more than 20 times its size in 2020. Costs of batteries are expected to drop with market growth. This downward price trajectory is already evident for lithium-ion batteries, currently the most deployed battery technology. Cost developments for lithium-ion batteries are shown in **Error! Reference source not found.**, with actual historic data to 2020 overlayed onto the modelled cost projections[9] to 2050. Actual and forecasted cost trends for lithium-ion batteries closely mimic

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[6] LCOS is defined as the total lifetime cost of the investment in an ESS technology divided by the lifetime cumulative energy (USD/MWh) or power (USD/MW) delivered by the technology.

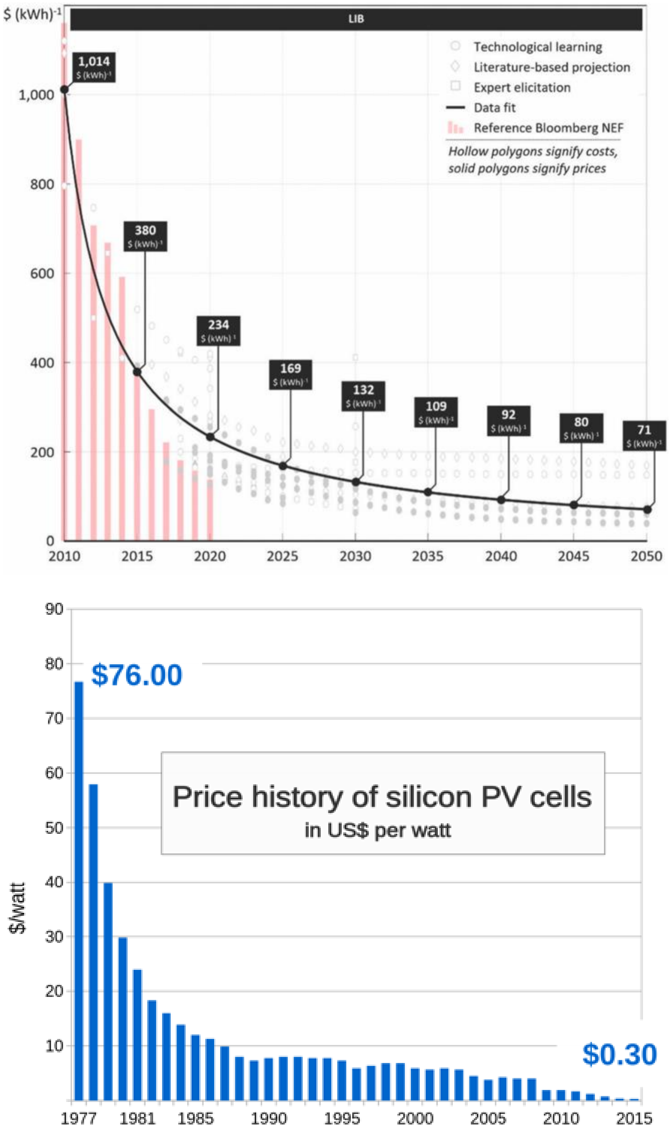
[7] The annualized cost of storage employs the standard annuity formula to the costs only which are then divided by an annual average of the cumulative lifetime energy (MWh-yr) or power (MW-yr) discharged.

[8] The LCOE is the lifetime cost of an electricity plant, divided by the amount of electricity it is expected to generate over its lifetime. This effectively shows how much each unit of electricity that is produced over the entire plant lifetime costs.

[9] Drawn using technology learning, literature-based projection, and expert elicitation.

the price history of crystalline silicon PV cells that saw prices fall from USD76 to USD0.3 per watt between 1977 and 2015 (graph insert on **Error! Reference source not found.**).

For emerging batteries with limited available data points[10], price projections were modelled to develop indicative cost trajectories. Modelling suggests several emerging BESS technologies have the potential to (i) achieve pack-level costs below USD 50/kWh by 2040 and (ii) are likely to be cheaper to produce than lithium-ion batteries[11].



Source: Bloomberg New Energy Finance & pv.energytrend.com

Figure 3: Consolidated and standardized pack-level CAPEX forecasts for lithium-ion batteries (LIB) to 2050 and the ***comparative historic price trend*** *for silicon PV cells.*

The cost trajectories modelled by the CMP SSS study are less aggressive than market claims, suggesting that BESS cost reductions might be achieved sooner if market conditions are favourable. Another noteworthy observation relates to the projection that **Fe-Air batteries are already predicted to achieve a cost of USD 11/kWh by 2040.** A significant price point because current estimations are that energy storage would have to be available **at less than USD 20/kWh to support a power system running on 100% VRE** (i.e. VRE baseload).

Projections have not been done for lifetime costs. The multitude of possible combinations between BESS technologies and grid use cases (and combinations of use cases if stacking is allowed) means it is not feasible to develop cost estimates and projections for all the service combinations. However, as production costs decline and performance characteristics improve, it should reflect in declining lifecycle costs.

Current and Projected BESS uptake

Developments of just more than 1.7 GW by 2027 were confirmed across the continent, i.e. 0.4% of the projected global BESS capacity of 358 GW by 2030. Considering Africa's rapidly growing power requirements and the already planned contributions from VREs, it is obvious that these existing commitments have not fully tapped into the potential for BESS on the continent. The BESS SSS study used existing data to model a "high scenario" in which it found the continent could potentially deploy approximately 4.8 GW by 2030 and 7.7 GW of BESS capacity by 2040 (**Error! Reference source not found.**). Even in the "high scenario" these projections are conservative compared to other estimates[12], giving preference to a reasonable expectation of BESS adoption high levels of implementation.

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[10] Reported data typically available for first generation cells.

[11] Lithium-ion batteries are constructed with expensive materials, meaning there is a material cost cap below which they will battle to fall. Lithium-ion batteries are also unlikely to provide long duration storage much beyond the 8 hours already achieved.

[12] For example, the Engie Report's "low carbon" scenario estimates the total energy storage capacity required to achieve the European Commission's 1.5°C target and AfDB's low-CO2 scenario for 2030 producing significantly higher energy storage capacity values.

The value proposition of a BESS investment is improved when its value is considered across

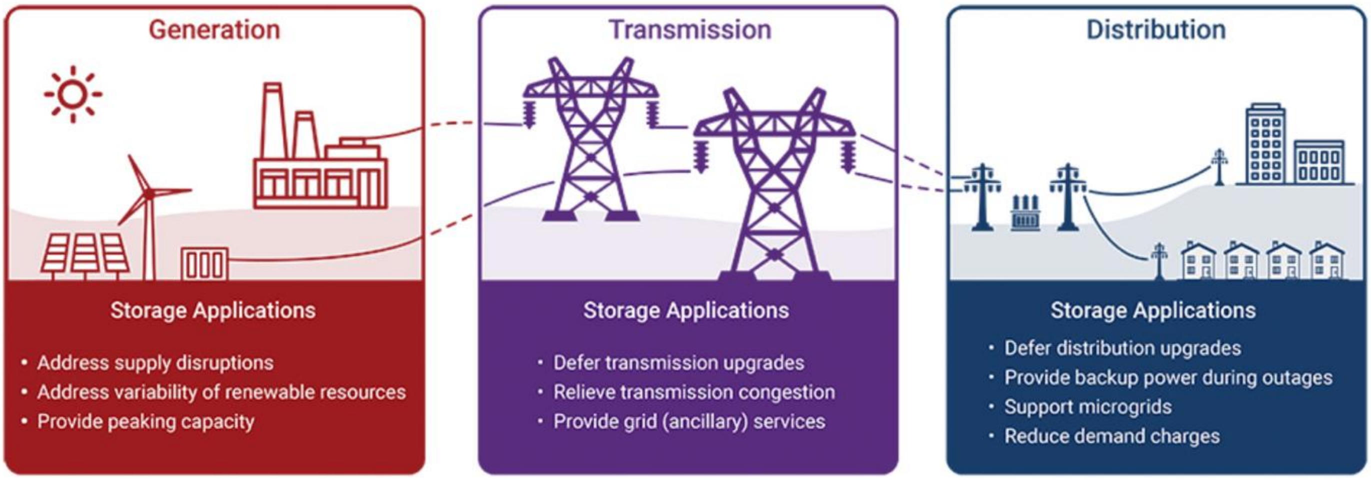

Figure 4: Services offered by utility-scale BESS (Source: https://clearpath.org/tech-101/intro-to-energy-storage/. For illustration purposes, not from the SSS)

Opportunities

Grid-scale BESS applications and stacking

BESS can be deployed for a range of grid applications or services, classified into four categories:

(i) bulk energy services,

(ii) ancillary services,

(iii) transmission and distribution infrastructure services and

(iv) customer management services.

This versatility is illustrated in **Error! Reference source not found.**.

The potential contribution from BESS depends on where in the power system it is located, who owns it, who can access the services, and how the services are valued and compensated.

Error! Reference source not found. is useful to demonstrate the concept of value stacking, recognising that every BESS can provide more than one of the services shown, either sequentially or at the same time. It can also provide services across traditional boundaries; a battery located at distribution level can support integration of VRE generation.

grid services. Revenue stacking through a multi-service business model was shown to materially enhance BESS project profitability. **This underscores the importance of a regulatory framework, electricity market and tariff structure that enables value stacking.**

Opportunities modelled for the CMP

While cognisant of the limitations of focusing on a single application, multi-service business models require detailed modelling at individual project level that is not feasible at a continent-wide level. **The BESS SSS study therefore modelled two distinct use cases: energy time-shifting and operating reserves.** This selection was based on several assumptions and considerations:

- BESS will most typically be owned by a vertically integrated utility[13].
- Utilities will operate BESS predominantly for energy time-shifting but also to provide operating reserves.

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[13] A power utility that combines generation, transmission, and distribution operations

- The two use cases are characterised by very different duty cycles which may favour different battery technology choices.
- The two use cases also mirror the traditional use cases for pumped storage.

Noting the lack of African experience with grid-scale BESS and thus a high level of uncertainty, the modelling demonstrated that for both the modelled use cases technology options are available that can deliver these services at a LCOS of between USD 0.18 and 0.19 per kWh. As already noted, the LCOS could likely be improved if the BESS can be used for additional services.

The modelling also noted remaining concerns regarding operating regimes and longevity of BESS technologies. These are included in the later discussion about barriers and challenges (Section **Error! Reference source not found.**).

Emerging BESS applications

The following emerging opportunities can maximise BESS benefits:

BESS in combination with solar PV or hybrid systems. As part of a hybrid solution that incorporates other technologies such as wind, solar and hydropower. When co-located and operated as solar plus storage, BESS forms part of an integrated power supply solution, but requires consideration at a national / regional / continental level to ensure functionality is optimally utilised.

Hybrid battery configurations. International examples[14] were identified where more than one type of BESS technology were combined into a hybrid battery system, exploiting the characteristics of each technology to provide an optimal solution and to access a broader range of grid services.

Off-grid BESS deployment. Off-grid applications include both minigrids, commercial and industrial projects. These present market opportunities to BESS developers as well as future grid integration and utilisation of the BESS assets as part of the power system.

Demand side response. Embedded generation and BESS are a significant part of the flexibility resources of an active distribution network. The business case for customer-sited ESS is considerably enhanced (retail tariffs) while the system benefits can still be leveraged with appropriate regulatory and tariff structures. Through aggregation customer-sited BESS can provide decentralised BESS capacity while on private balance sheets.

Second-life batteries. Batteries retired from electric vehicles (EVs) and deployed for grid applications are a critical but still unknown piece of the puzzle for grid-scale BESS deployments. When retired at 80% state of health, these batteries potentially have another 40% of their life available. The demand for EV batteries is estimated at 1,300 to 2,340GWh in 2030, seven times more than the 180GWh predicted for stationary applications.

Battery recycling. Closely related to second-life batteries is battery recycling and its significant potential to influence both the BESS technology mix and cost trajectories. Recycling can reduce the battery material and energy intensity of battery production by 40–50%. It also enables properly managed disposal of toxic materials.

Barriers or challenges

Technical barriers

Because of its relatively recent inclusion in power systems, most international electricity markets consider BESS an emerging technology, despite some technologies already being commercially established and successful. Experience in the African context is even more limited with very few grid-scale BESS projects that are operational.

As an emerging technology it is expected that technical performance will continue to mature and improve. Already, rapid and significant improvements have been seen across most performances metrices. Many of the remaining

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[14] Example: A 50 MW/50 MWh Lithium-ion battery plant combined with a 2 MW/5 MWh vanadium-redox flow battery (VRFB) that exploits the high power density (but shorter cycle life of ~ 3,000 cycles) of LIBs and the heavy-cycling capabilities of VRFB (~ 20,000 cycles).

technical barriers relate to the technical understanding and integration of BESS into the power system. The following were identified as the most common technical barriers:

- **Performance degradation.** Two key technical challenges to large-scale BESS adoption are capacity degradation (~3% per year) and round-trip efficiency loss. If this can be addressed it will deliver extended BESS service life, improved system economics, longer system warranties, and decreased environmental impacts associated with raw material extraction and manufacturing. Improvements are already evident with most grid-scale lithium-ion BESS deployed today lasting at least 10 years with a relatively small decrease in performance (approx. 20% capacity loss after 10 years).
- **Low-quality equipment and installation**. Inferior BESS equipment and poor-quality installations will impede the adoption and proliferation of batteries in emerging markets, and threaten operational, reliability, and safety issues across power grids.
- **Technical understanding of use cases and applications**. Lack of experience with the range of services that BESS can provide across transmission, distribution, and generation applications will stand in the way of optimal adoption and deployment. Related to this underutilisation of BESS is the difficulty of accurately attributing system- or economy-wide benefits to individual BESS projects, and the lack of mechanisms for compensation of these services. This will undermine project feasibility and curb investment.
- **Lack of clear interconnection rules**. Very few countries and sub-national jurisdictions have established interconnection requirements for BESS: a unique asset requiring tailored specifications. This lack of clarity around interconnection has the effect of extending project timelines, increasing costs, and even deterring adoption in certain markets.
- **Inadequate requirements for safety.** A key technical barrier in certain locations is the lack of adequate and complete technical specifications for safety. Safety codes and standards must be in place and will have to evolve to keep up with rapidly changing BESS technology.
- **Inconsistent technical standards**. A patchwork of inconsistent, confusing, or incomplete technical standards – whether for interconnection, safety, or other factors – adds complexity, time to completion and costs throughout the value chain, which can have the effect of limiting new BESS deployment and discourage developers and owners from operating across markets.
- **End-of-life management for BESS equipment.** A recurring concern relates to the appropriate management of BESS at end of life and responsible handling of any hazardous materials. Typically end of life is managed in two stages: (i) redeployment for a different application with lesser performance requirements before (ii) it is finally removed from service for treatment and disposal. Unfortunately, few jurisdictions have established provisions and frameworks for this and currently there is a lack of battery recycling infrastructure on the continent. This will add to lifecycle costs and will hamper access to finance if suitable plans for handling of waste cannot be demonstrated.

Regulatory and investment barriers

Regulatory and investment challenges are closely related, with investment challenges and business models directly dependent on the market design and enabling regulatory framework. The most notable of this is value stacking. Value stacking is critical to the profitability of BESS investments and electricity markets that restrict BESS participation to a narrow range of grid services limit the value proposition of BESS and increase project risks. Riskier projects are associated with higher financing costs from commercial banks and reduce project bankability limiting wide-scale adoption of BESS projects.

The following barriers and challenges were identified as preventing optimal adoption of BESS:

- **Low levels of awareness among energy sector stakeholders** (e.g., governments, regulators, financiers, system operators, utilities) of BESS technologies and their potential benefits to the electricity network.
- **Lack of policy support.** BESS has not yet been integrated into country policies, national targets, strategies, or planning documents and they are not provided for under financial incentives (e.g., grants, direct/indirect subsidies, tax breaks).
- **Unclear permitting and licenses requirements.** Unclear requirements, duplication and lengthy compliance procedures cause delays, increase costs and discourages investment. Similarly, market rules are generally discriminatory, confining market participation, interfaces and monetization of services, which discourages investment.
- **Ancillary and grid management services.** The value of ancillary services (e.g., balancing, non-frequency services, congestion management) that can be provided by BESS are not recognised and are not compensated under most current tariff structures.
- **Grid codes.** Outdated grid code rules don't provide specific guidance for BESS technologies along with the capability to enforce compliance from grid connected BESS projects.
- **Taxes, surcharges, and levies.** Double taxation and charges associated with BESS since it often functions as both a consumer and a generator of electricity. These extra costs can discourage the business case for investing in new projects.
- **Network operator involvement.** Insufficient rules on the role of the network operator in terms of potential ownership and operation of BESS. The network operator often has a natural monopoly on grid infrastructure assets which can potentially discourage investment by private developers without fair market rules.
- **Definitions and standards.** Lack of a legally binding and technology neutral definition for energy storage in regulations that help legitimize the use of BESS as an alternative to traditional grid reinforcement projects. Likewise, standards often require updating to ensure BESS installations adhere to safety, performance, and reliability requirements.
- **Remuneration and tariffs.** Inefficient and bundled tariff structures (i.e. that are not time differentiated) that don’t allow for cost effective charging and/or full compensation of the value that BESS can provide to the grid, will discourage investment in BESS.
- **Current market structures and regulations.** The limited value of BESS under current electricity market regulation, limiting multiple revenue streams and/or compensation for ancillary services which limits the bankability of projects.
- **High upfront cost of technology.** BESS is still an expensive technology even though prices have been declining.

In addition to the above, BESS projects are also subject to the hurdles common to infrastructure investment on the continent. These include high cost of capital, financial constraints of off-takers (local utilities and consumers) and construction and operating risks in some jurisdictions.

What is needed to unlock the potential?

The most important requirement to ensure BESS potential is exploited and optimally deployed is an energy storage or BESS-specific regulatory framework that recognises the unique features of this asset in the power system, provides stability over the life of the BESS investment and ensures the long-term sustainability of the BESS industry. The study strongly cautioned against the assumption that a framework adequate for VRE is also adequate for BESS integration. While each country or electricity market will have its own unique characteristics and requirements, it should aim to address the non-technical barriers identified in the previous section. An appropriate policy and regulatory framework should:

- **Define or classify energy storage as a separate, unique asset in the power system.** BESS has most commonly been classified as a generation asset, although it is sometimes also treated as a consumer and potentially a transmission asset. Each of these definitions are too narrow for the versatility offered by BESS. Inappropriate classification also creates ambiguity that could result in double grid charges, duplicate licensing requirements, excessively restrictive network connection requirements, among others. The definition should also remain technology agnostic to avoid technology lock-in.
- **Create consistency across regulatory requirements.** All aspects of the regulatory framework should be consistent and BESS friendly, including permitting and licenses, grid codes, and standards; processes and requirements should be streamlined and efficient, eliminating any duplication and without imposing excessively onerous requirements inherited from traditional power system assets.
- **A portfolio approach to developing flexibility resources.** A portfolio approach is required to efficiently invest in flexibility resources for the power system while delivering resource adequacy. The study recommended a full continental ESS strategy be developed that considers the full portfolio of feasible technologies (short-, medium- and long-duration storage) and their deployment across the entire power system including demand response or behind the meter systems.
- **Support BESS-friendly business models that enable revenue stacking.** This includes appropriate tariff frameworks that fairly compensate BESS for various grid services and use cases, time-differentiated tariff structures that reflect the time value of energy on the power system, and non-discriminatory access to BESS services across traditional boundaries.
- **Inclusive electricity market regulation.** Designing an efficient market and fair remuneration structure will be important to the CMP and AfSEM, ensuring BESS capacity is developed and can be utilised for the benefit of the broader power system.
- **Reduced costs.** Financial support, subsidies, waived import duties and tax incentives can all be used to lower the high upfront cost of BESS equipment and encourage investment.

Additional recommendations take a wider perspective within the larger context of the circular economy and value chain to encourage optimal absorption of BESS into the power system:

- **Demand-side response (DSR).** Distributed and embedded ESS can critically contribute to energy storage capacity and flexibility resources on the grid. It will be an essential part of an optimal power system and should be included in a portfolio of flexibility assets and technologies.
- **Off-grid BESS opportunities.** Additional work is required to fully understand the scope and potential of the off-grid market.

This market segment offers additional opportunity for BESS developers, improving market attractiveness and encourage investment on the continent.

- **Second-life batteries.** The opportunity to redeploy retired batteries (second-life use or echelon utilisation) should be explored as a potentially cost-effective solution for grid-scale BESS purposes that also optimises the full lifecycle value of EV batteries and significantly extends the useful life of the original cells.
- **Battery recycling.** Suitable responses to end of life batteries from grid-scale applications must be developed in early deployment stages to avoid facing a later, large scale hazardous waste problem.
- **Pilot projects.** Carefully designed pilot projects, designed to identify locally relevant opportunities and test BESS business models in Africa is strongly recommended.

Conclusion

BESS will contribute crucially to the new and evolving grid paradigm and system requirements, offering increased reliability, resilience, grid modernisation and flexibility for the integration of a diverse and distributed generation portfolio connected to diverse energy users. Unsurprisingly, BESS is experiencing a period of rapid deployment growth across the world, and even amid economic downturns, analysts expect this trend to continue. Accelerated growth prompts increased investment in technology development and increasingly competitive pricing.

Lithium-ion batteries are currently dominating the global market, delivering up to eight hours storage and showing minimal degradation over 10 years. But other technology options are emerging fast that could cater more cost-effectively for evolving system requirements. Already several options are promising to have lower costs, lower environmental impacts, longer duration storage and greater cycle life. Cost trends show that breaking the USD 20/kWh cost threshold, believed necessary to support a 100% VRE power system, is likely within the foreseeable future.

Confirmed development of BESS across the continent is still small compared to global projections, less than 0.5% of the global BESS capacity of 358GW by 2030. Considering Africa's rapidly growing power requirements and the already planned contributions from VRE, these commitments do not fully reflect the potential for BESS on the continent. A conservative estimation, not including all power pools for lack of data, suggests that 4.8 to 7.7GW installed capacity is reasonably possible by 2030 and 2040 respectively.

All modelling has severe limitations, as expected for a non-conventional and multi-application or multiple use-case technology such as BESS. Simplifications introduced for the sake of the modelling contribute to an underestimation of the value and potential for BESS in the power system. Optimal inclusion of energy storage should translate into enhanced grid flexibility and strengthened system resilience in the face of climate, consumer and technology developments – a larger contribution than achieving the integration of higher shares of VRE (represented by the two modelled use cases).

Given the complexity of BESS – the multiple applications and use-cases, the variables associated with markets and system requirements – it is impossible to fully explore the potential value of BESS to the continent. At best the study provides a high-level view of BESS potential in Africa's power system. More detailed, context specific modelling is necessary to accurately assess the potential of multi-service business models. At the same time, more strategic level modelling is necessary to guide policy and investment of a continental portfolio and help navigate an evolving portfolio mix over the planning horizon.

Some non-technical and technical barriers still stand in the way of optimal adoption. With rapid technology advances, the remaining technical barriers increasingly relate to the understanding and integration of BESS. Inadequate regulatory frameworks were identified as the chief impediment to BESS deployment. As BESS mature and demonstrate their viability in various contexts and capacities, policies and regulations will want to encourage broader deployment while ensuring energy systems maintain and enhance their resilience. Particularly important considerations when it comes to formulating an enabling policy and regulatory environment include the need to (i) remain technology-agnostic allowing development across all technology types, (ii) make provision or allow for value stacking and (iii) avoid incorporating energy storage under conventional / traditional regulatory frameworks designed to regulate a single aspect, but rather to develop a policy and regulatory framework specific to energy storage that can accommodate the full spectrum of applications.

To grow the understanding of BESS, it is strongly recommended that pilot projects are implemented that are carefully designed to provide the required learning and testing of BESS business models in Africa.

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